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Aurora intensity conversion and distribution simulation

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Abstract. For the upper atmospheric wind field measurement, the conversion relations between the unit of auroral (airglow) intensity Rayleigh and illumination, luminance, height of atmosphere, the photon number are derived. The auroral volume emission rate (VER) of $O(^1S)$557.7nm and $O(^1D)$630.0nm with height is presented. The VER peak values are 668R and 2630R respectively. The results can provide theory for light illumination and brightness of detecting upper atmosphere.

Introduction

The light source is aurora (airglow) for remote sensing detection the wind field (temperature, wind velocity and volume emission rate, etc.) in the upper atmosphere (80-300km) by passive methods [1]. The most important spectral line is atomic oxygen green line $O(^1S)$ 557.7nm, oxygen red line $O(^1D)$ 630.0nm and $O^+(^2P)$732.0 in the visible range. The aurora detected by CCD is used in Rayleigh unit, but the aurora normally expressed by illumination and luminance. In view of this, for purpose of unified level data and calculated, the relationship between the intensity and illumination of aurora is researched in this paper, the conversion relation is given, and changes rules of $O(^1S)$557.7nm and $O(^1D)$630.0nm with height are further given. The conclusion established a foundation for ground-based detector; furthermore, it can provide a guide for conversion of low light illumination's intensity.

Aurora intensity for different unit

When the upper atmospheric wind field is measured by satellite remote sensing, the primary data measured by CCD is the intensity I denoted by volume emission rate (VER), which is the photons emitted from an extended column per unit area in photons/s.m^2. The unit Rayleigh/R is used to express the auroral intensity. 1 Rayleigh (1 R) is defined as a column emission rate of 10^{10} photons per square meter per column per second [2], which is expressed per unit solid angle by

$$1\,[\mathrm{Rayleigh}] \equiv 1\,[\mathrm{R}] \triangleq \frac{10^{10}}{4\pi}\,[\frac{\mathrm{photons}}{\mathrm{s\,m^2 sr}}] \tag{1}$$

for the pointolite, the illumination is $E = I / r^2 \cos i[\mathrm{lx}]$, Brightness is $L = d\Phi / \mathrm{d}S\cos\theta \mathrm{d}\Omega$, where I is the intensity in candela/cd, i is the angle between direction of light projection and the direction of small patches, r is the distance, θ is the angle between cross section and projection surface. The unit of illumination is lux/lx. 1lx can be expressed by $1\mathrm{lx}=1/(683 v(\lambda)\, e(\lambda))\ \mathrm{W \cdot m^{-2} \cdot sr^{-1}}$.where $v(\lambda)$ is vision function, $e(\lambda)$ is distribution function. The aurora can be considered as a pointolite. So the relation of illumination and brightness is $E = 4\pi L$. In order to calculate the photons into detector lens per second, fig.1 shows the theoretical model. Parameters are supposed: The lens' field-of-view (FOV) is Ω, the transmittance of optical system is τ, quantum efficiency of detector is η, sectional area of lens is A m^2, the inclination of the atmosphere to the lens is $a(R) = A / R^2 sr$, and the VER expressed by $V(r)$ in Rayleigh. The photon number received by CCD is as follows:

$N = \eta \cdot \tau / 4\pi \int_0^R V(r)dr$ photon/s m^2 sr .According to the defination of the auroral intensity[2], the photons I in Rayleigh is $I = 10^{-10} \int_0^\infty V(r)\mathrm{d}r$ Rayleigh .Due to $a(R) = A / R^2 sr$, and the area of sphere surface corresponding with lens' aperture angle Ω is Ωr^2, the received energy into detector per second is

$$L_E(A) = \frac{10^{10} I\Omega A^2 \eta\tau \cdot hc}{4\pi\lambda}[\mathrm{W}] \tag{2}$$

According to calculate, the relations between auroral intensity I in Rayleigh and the light illumination $E[\mathrm{lx}]$, luminance $L[\mathrm{cd/m^2}]$ are

$$E(I(R)) = \frac{170.75 v(\lambda)e(\lambda) \cdot 10^{10} A\eta\tau hc}{\pi\lambda} \cdot I\,[\mathrm{lx}] \tag{3}$$

$$L(I(R)) = \frac{170.75 v(\lambda)e(\lambda) \times 10^{10} AhcI\eta\tau}{4\pi^2\lambda}[\mathrm{cd/m^2}] \tag{4}$$

where h is Planck constant, c is velocity of light, λ is wavelength (unit m).

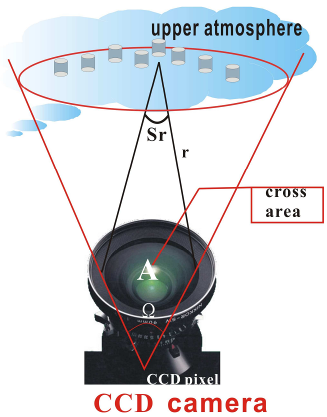

Fig. 1. The model of aurora detected by CCD.

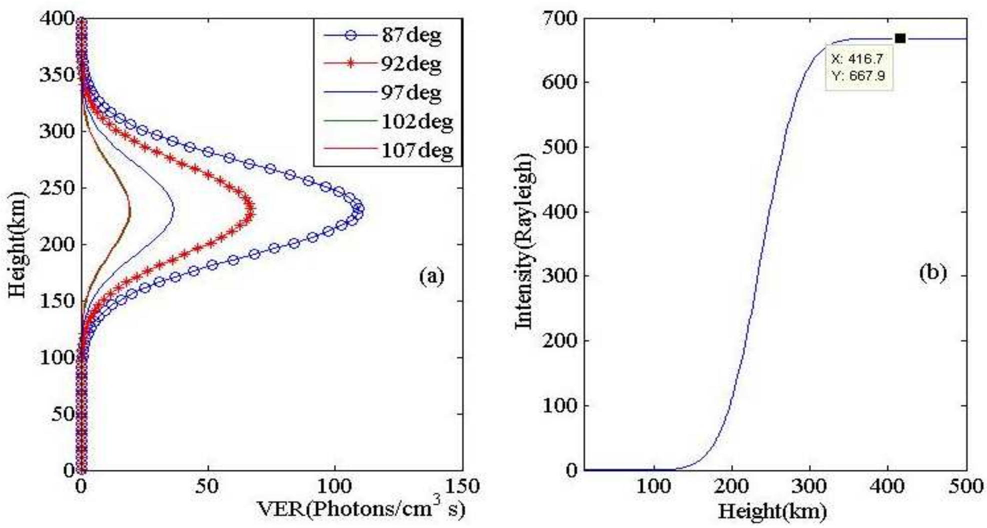

Fig. 2. The VER and intensity of O(^{1}D) 630.0nm varied with the height.

For O(^{1}S)557.7nm and O(^{1}D)630.0nm, supposed $v_{557.7nm}$≈1, $v_{630.0nm}$≈0.2, $e(\lambda)$=1, τ=0.33, η=0.5. According to the data of WINDII (Wind Imaging Interferometer) [1], take the aperture area A= 32.7cm^2. Substituted in Eq. (7) get the conversion relations: $E(557.7)=9.502\times10^{-10}I$ [lx], $L(557.7)=7.56\times10^{-9}I$ [cd/m^2], $E(630.0)=1.682\times10^{-10}I$ [lx], $L(630.0)=1.34\times10^{-9}I$ [cd/m^2]. The data of conversion data is as table1.

Table1 Conversion data of the auroras of O(^{1}S)557.7nm and O(^{1}D)630.0nm

I(kR)	E(lx)		L(cd/m^2)		Φ(mW/m^2)	
	O(^{1}S)557.7 nm	O(^{1}D)630.0 nm	O(^{1}S)557.7 nm	O(^{1}D)630.0 nm	O(^{1}S)557.7 nm	O(^{1}D)630.0 nm
1	9.50×10^{-5}	1.68×10^{-5}	7.60×10^{-6}	1.34×10^{-6}	13.9×10^{-5}	24.6×10^{-6}
50	4.75×10^{-3}	8.41×10^{-3}	3.78×10^{-4}	6.69×10^{-5}	6.69×10^{-3}	1.23×10^{-3}
80	7.60×10^{-3}	1.35×10^{-3}	6.05×10^{-4}	1.07×10^{-4}	11.1×10^{-3}	1.97×10^{-3}

The auroral intensity varied with the atmospheric height

In order to obtain the integrated VER, the VER profile of O(^{1}D) 630.0nm fitted with Gauss function is given by $V=V_p\exp[-(z-h_p)^2/(2W^2)]$ [3]. Where V is VER in photons.cm^{-3}.s^{-1}; z is height in km; V_p is the peak value; h_p is the height in km corresponding with V_p; W is the spectral width of Gauss aurora. Take the data on 04JAN95 of WINDII and F10.7=76.9 [4], the VER of O(^{1}D) is obtained as

$$V=\begin{cases}(214.1279\cos^{\frac{1}{e}}\chi+35)\exp\{-[z-(-0.18586(214.1279\cos^{\frac{1}{e}}\chi+35) \\ \qquad +250.842)]^2/[2(8.03\cos\chi+40.0751)^2]\} \quad (\chi<87^{\circ}) \\ [798.6607(\cos\chi+0.25)^{1.8}+16.7055]\exp\{-[z-(-0.18586(798.6607(\cos\chi+0.25)^{1.8} \\ \qquad +16.7055)+250.842)]^2/[2(8.03\cos\chi+40.0751)^2]\} \quad (87^{\circ}<\chi<104.5^{\circ})\end{cases} \tag{5}$$

where χ is solar zenith angle. And the integrated VER is

$$I=\frac{1}{10^6}\int_0^z V\,dz \text{ Rayleigh} \tag{6}$$

For O(^{1}S)557.7nm, according to the Chapman mechanism[5], the VER varied with the height can be obtained by $\xi(z)=V_e\exp[1-b_e-\sec\chi_e\exp(-b_e)]+V_f\exp[1-b_f-\sec\chi_f\exp(-b_f)]$ [6]. Where V_e, V_f are peak of the E layer (100-300km) and F layer(300-500km) respectively. According to the data on 25MAR1992 of WINDII [6] and F10.7=186 [7], the VER and integrated VER are deduced by

$$\begin{aligned}\xi(z)&=207.1048\exp[1-\frac{z-176.5597}{30.2096}-\exp(-\frac{z-176.5597}{30.2096})] \\ &+427.9441\exp[1-\frac{z-99.278}{8}-\exp(-\frac{z-99.278}{8})]\end{aligned} \tag{7}$$

$$I=\int_0^z \xi(z)dz \tag{8}$$

The VER and integrated emissivity of O(^{1}D) and O(^{1}S) varied with the height can be simulated by computer as fig.2 and fig.3 respectively. As seen from fig. 2 and fig.3, the VER is small under the range of 0-100km, the simulated result is about zero because of the overall photons reached to the detector is very limited along the sight; when height is 100-300km, the VER reaches the peak value. And the peaks of O(^{1}S)557.7nm appear at 100km and145km. As seen from the fig. 2(b) and fig. 3(b), the intensity of detector would be constant at the pointcoordinate (416.7km,667.9R) and (410.8km,2631R) respectively. So the maximum integral VER of O(^{1}D) and O(^{1}S) can be respectively intended to 668R and 2630R. According to the data of WINDII, the simulated integrated emissivity is about 110R [1]. The simulated result of ground-based measurements in this paper will provide the theoretical direction for atmospheric wind field measurement.

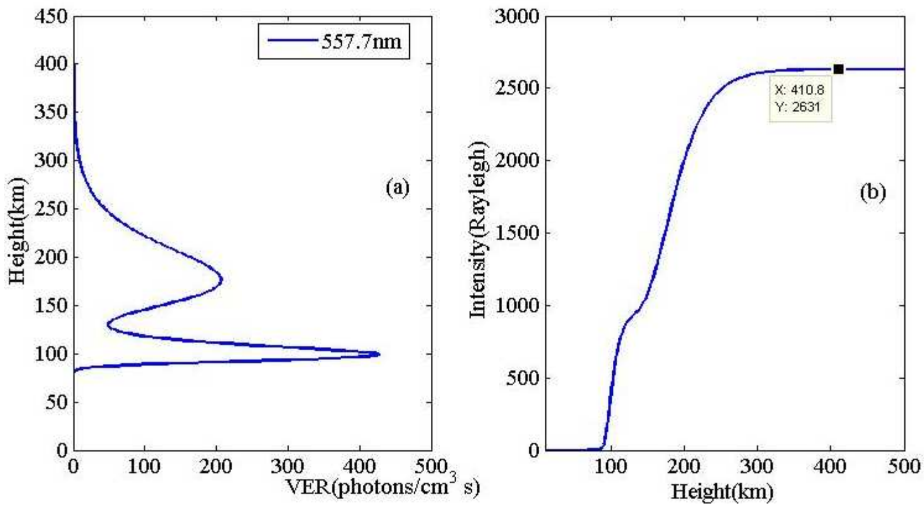

Fig. 3. (a) The VER of O(^{1}S)557.7nm varied with the height, (b) Integrated VER of fig 3 (a)

Conclusions

The conversion relation between the unit of auroral intensity Rayleigh and the number of photons is deduced theoretically. The conversion formula can be provided a convenience between detected energy and photon number. The relations of auroral intensity of 557.7nm and 630.0nm varied with the height have been gained. The auroral VER varied with the height are primarily analyzed and presented in Rayleigh. The intensity received by detector under different height is expressed by integrated VER. The conclusion of this study would provide theoretical direction, which makes the conversion and unit representation to further atmospheric wind field measurement more convenient. And this paper can also provide the theory and reference for conversion of low-light illumination's intensity.

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